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(56) Documents Cited
GB 2261788 A WO 97/42518 A1 DE 004318548 A1
US 5657027 A US 4626859 A

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(54) Abstract Title
Direction finding aerials

(57) The phases of the received signals at three or more spaced antenna are compared to determine the angle of arrival. In the main embodiment, the signals from three vertically polarised dipoles, arranged in a triangle are selectively switched in sequence to determine phase differences B_1 and B_2 from which the angle of arrival θ is determined using the formula: $\theta = \tan^{-1}\left(k\frac{B_2 - B_1}{B_2 + B_1}\right)$, where $k = \sqrt{3}$ for equilateral triangle and varies according to the relevant angles in an isosceles triangle. A phase-locked loop may be locked to the signals to derive an indication of bearing. The unit may be a hand held device from determining the direction to a distress beacon on VHF sea or aircraft channels. The dipoles may be connected through transmission line sections to prevent the currently non-selected dipoles from affecting the selected dipole. The system may use be superheterodyne receiver.

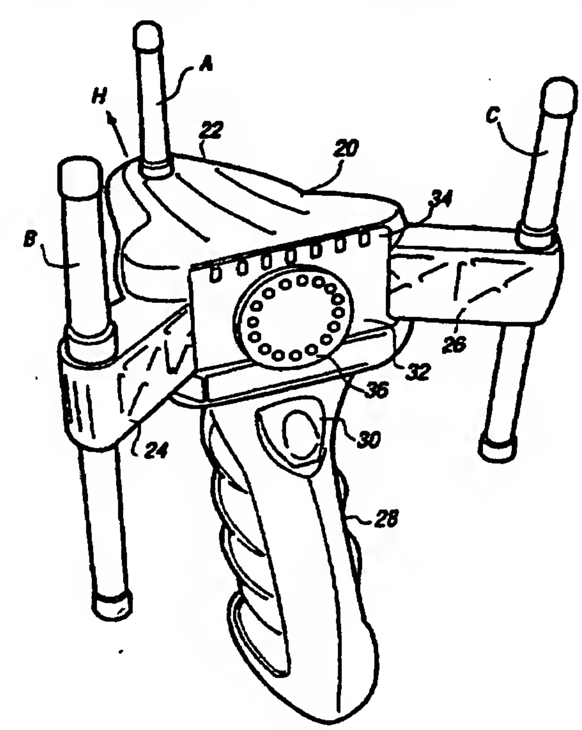

FIG. 2

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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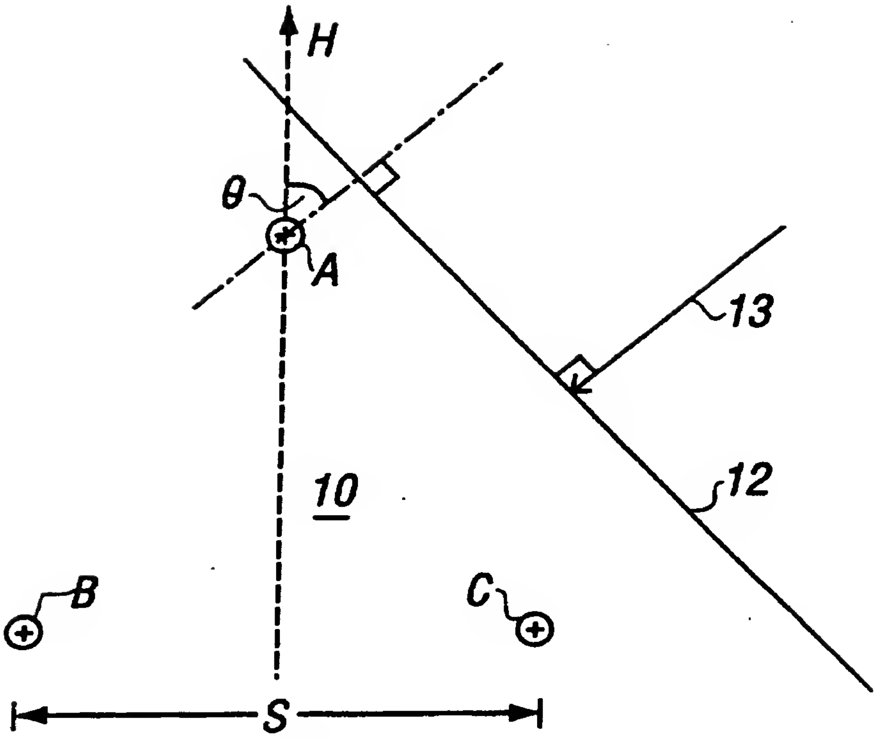

FIG. 1

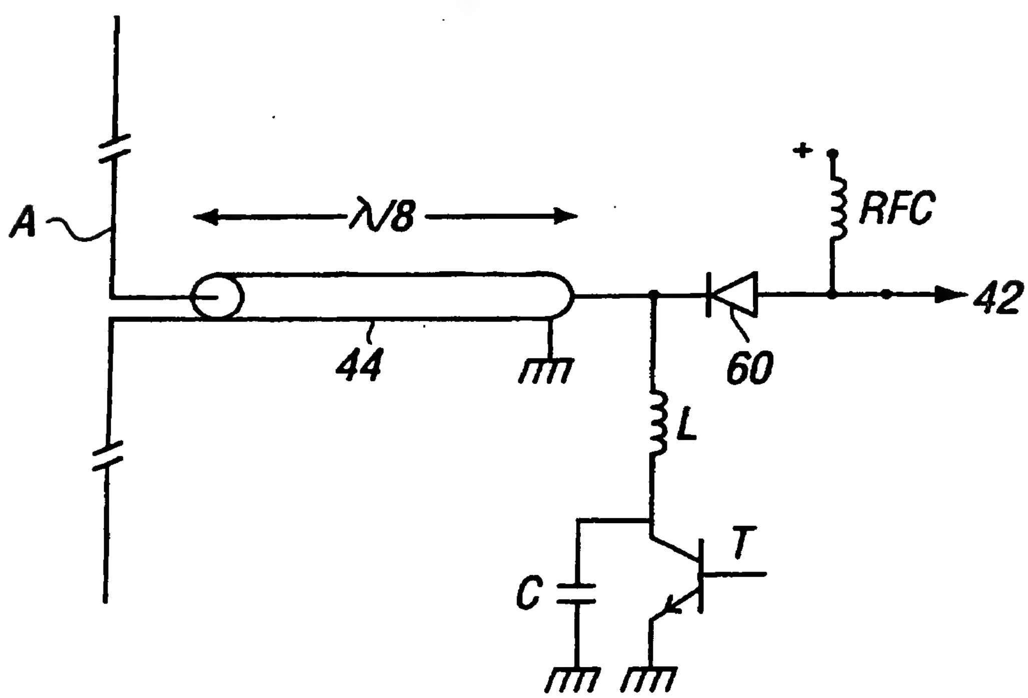

FIG. 4

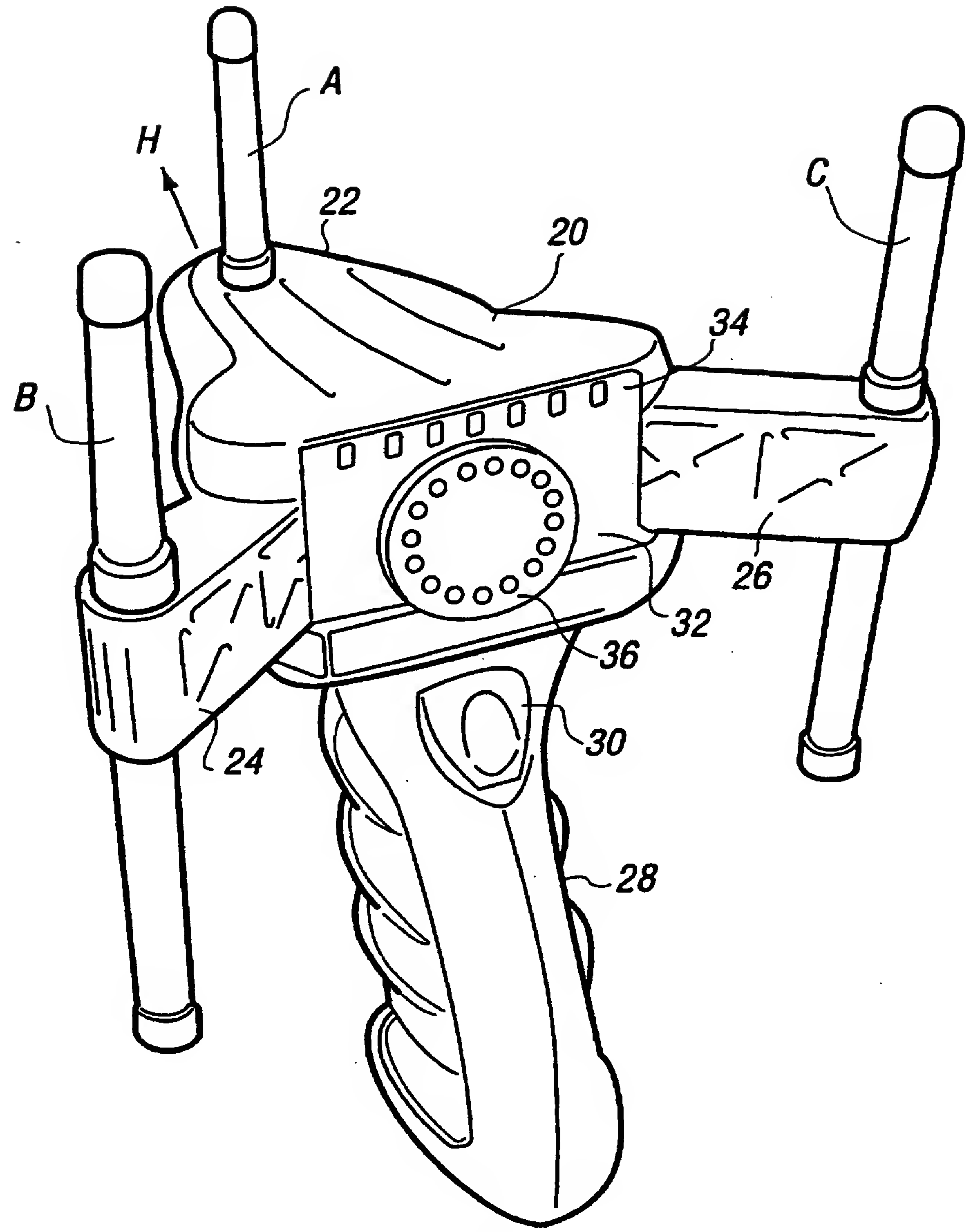

FIG. 2

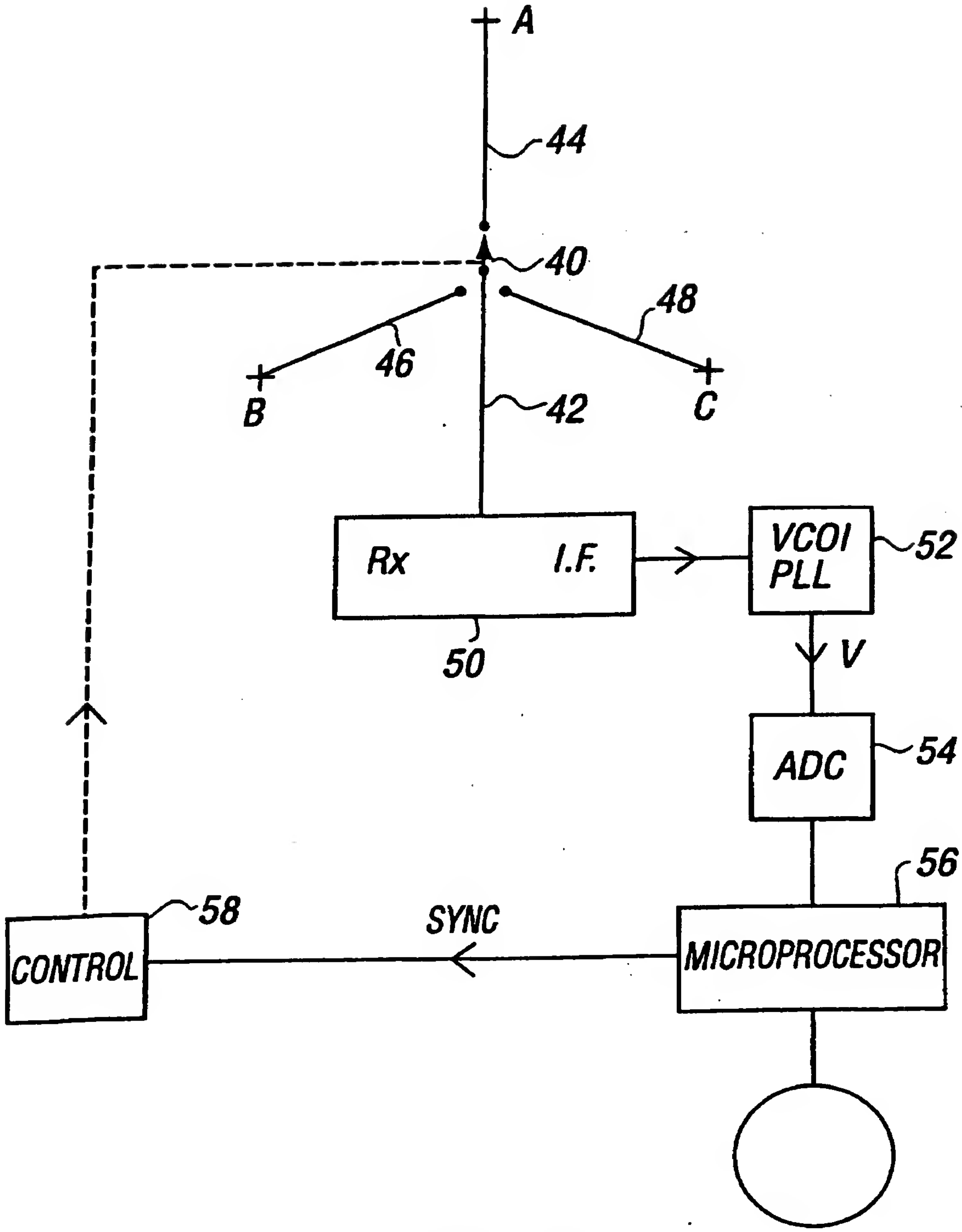
A
44
40
48
46
B
42
C
Rx
I.F.
VCO/
PLL
52
50
V
ADC
54
56
58
SYNC
CONTROL
MICROPROCESSOR

FIG. 3

Title: DIRECTION FINDING UNIT

This invention relates to a direction finding (DF) apparatus and to an aerial system for use with DF apparatus.

There is a need for a portable DF unit which can be held and operated by an individual. One such situation arises where it is necessary to locate a transmitter, such as a distress beacon, at sea, where adverse conditions are to be expected.

More particularly, a search vessel may be sent out to locate the vessel in distress or a person in the sea who is equipped with a distress beacon transmitter. Considerable benefit would be obtained by having a hand-held DF unit in the search vessel that can be used in a manner to readily align with the heading of the vessel and to provide bearing information to enable the search vessel to head toward the source of the incoming signal. In considering the design of a DF unit, in practice it is desirable that the unit receive signals in at least one, and preferably both, of two VHF bands, namely the aircraft band at 121 MHz and the marine band at 156 MHz. A distress channel is allocated in each band. However, direction finding is not restricted to reception of signals from distress beacons. It may be employed more generally on incoming signals.

Proposals have been made for obtaining direction finding information from the use of an array of spaced aerials. That is the aerials are spaced in two dimensions. The aerials are conventionally mounted in a horizontal plane with vertical polarization. The relative phase at which an incoming wavefront is received at the spaced aerials is a function of the angle at which the wavefront arrives at the array and of

the spacing of the aerials. Systems have been devised to extract bearing information using three or more aerial elements at VHF, where significant phase differences are exhibited at moderate element spacings. Reference may be made to published patent specifications GB 2 124 849 and GB 2 121 651. The installations described are particularly designed for land mobile use, specifically for mounting on a vehicle. A different approach using an array of four elements at VHF is described in GB 2 261 788 in which by sequential switching and cooperation of the elements a swept beam is obtained. The installation as described is intended for mounting on a search vessel.

There still remains, therefore, a need for a hand-held unit, particularly one capable of being used in search activities at sea. A unit embodying the present invention and meeting this requirement will be described below.

Mention has been made of two VHF bands of particular interest: the 156 MHz Marine band provides five channels which employ narrow-band frequency modulation (NBFM); and the 121 MHz Aircraft band provides two channels which employ amplitude modulation (AM). Each band has a designated distress frequency 156.80 MHz and 121.50 MHz respectively. 156.8 MHz is used as a distress frequency by vessels, i.e. by a transmitter aboard the vessel. 121.5 MHz is used as the airband distress frequency and by beacon transmitters carried by survival jackets to be worn by a person in the water. The description that follows will therefore have particular reference to these bands which are allocated in the UK although it will be apparent that the teaching of the present

invention can be applied at other frequencies.

Aspects and features of the present invention for which protection is sought are set out in the Claims following this description.

The invention and its practice will be further described with reference to the accompanying drawings, in which:

Fig. 1 is a diagram illustrating the phase relationship established by an incoming wavefront on an aerial array having three elements at the apexes of an equilateral triangle;

Fig. 2 is a perspective view of a handheld unit embodying the invention;

Fig. 3 is a schematic circuit diagram of the aerial system including the aerial array and switching arrangement for it, together with the processing, control and display circuitry; and

Fig. 4 shows the feedpoint connections of one dipole to an aerial switching arrangement.

Fig. 1 illustrates an array 10 of three identical aerial elements A, B and C located in a plane at the apexes of an equilaterial triangle of side S. An incoming wavefront 12 is shown arriving in the direction of arrow 13 from a transmitter (not shown) whose bearing is to be determined. The wavefront 12 is normal to the direction 13 of the transmitter. The signals induced in the three aerials have phase differences proportional to the differences in path lengths to the wavefront.

A reference datum or heading H for direction finding with array 10 is conveniently taken as projection of the bisector of the apex angle of the triangle at which the aerial A

located. Aerial A acts as a reference element as will be described. The two sides AB and AC of the triangle thus each lie at 30° to the reference heading H. The bearing of the transmitter being located is θ with respect to heading H.

The DF apparatus to be described provides two phase difference measurements. One is the phase difference β_1 between the signals induced in aerials A and B by the incoming wavefront 12. The other is the phase difference β_2 between the aerials A and C induced by this wavefront.

It can be shown that for an equilateral (60°) triangle the bearing θ is given by

$$\theta = \tan^{-1} [\sqrt{3}.\frac{\beta_2 - \beta_1}{\beta_2 + \beta_1}]$$

The phase differences β_1 and β_2 in the above expression are positive or negative depending on whether the signal in aerial A leads or lags the signal in aerials B and C respectively. In any bearing direction there will be equal magnitudes of β_1 and β_2 from signals arriving from opposite directions, i.e. 180° apart. The maximum value of β_1 and β_2 is given by $2\pi S/\lambda$ (radians) where λ is the wavelength of the received signal.

A balance is achieved between providing a sufficient working range of the values of β_1 and β_2 for accurate detection purposes and maintaining a compact array for a hand-held unit. A spacing S of about 28 cm achieves this balance. It also fits with other aspects of electrical performance discussed below with reference to Fig. 4.

Referring now to Fig. 2, this is a perspective view showing the exterior appearance of a hand-held unit

incorporating an equilateral triangular array of three aerial elements as described above and into which the DF circuitry can be built. The aerials A, B and C are identical vertical dipoles.

The unit has a body or housing 20 of a generally triangular shape as seen in plan. The reference aerial A is mounted vertically through a nose portion 22 of the body to have its centre feedpoint contained within the body 20, short arms 24 and 26 extending from the other two apexes of the body. At the ends of arms 24 and 26 the other two aerials B and C are mounted vertically to extend through the arms with the feed point of each dipole within the arm. For compactness the dipoles may be helically wound as is well known in aerials for VHF hand-held radios. The antenna A which lies on the reference heading H, is held pointing forward by the operator. To carry the unit, it is provided with a depending handle 28 toward the rear of the body which is used to house battery cells for powering the unit. The handle is provided with a thumb-operated power switch 30. At the rear of the body 20 between aerials B and C, and facing the operator is a control and display panel 32. The panel may, for example, have switches and indicators 34 for selecting and displaying channels or other functions. It also has a bearing-indicator display 36. For the purposes of the present unit, the bearing indication does not have to be given with a high degree of precision though the internal bearing calculation is much more precise. The unit is intended to enable the crew of a search vessel to head the vessel onto the bearing of the signal received from the transmitter being

located until visual contact is made. For example, the display may use a circle of 16 LEDs, providing a resolution of 22.5° on the display. Conveniently an uppermost LED indicates a zero bearing. Thus in use the operator of the hand-held unit can align its reference heading H to the heading of the vessel with the aerial B and C to port and starboard respectively as seen by the user.

Fig. 3 illustrates the switching arrangement by which the aerials are selectively connected to a receiver for a phase measurement to be made on the signal from the selected aerial. The aerial and switching arrangement is such that while one aerial is selected the other two are effectively isolated from having any effect on the aerial being measured.

The aerials are selected by a three-way switch 40 for connection to a common cable 42. Aerials A, B and C have their centre feedpoints respectively connected to the switch 40 by equal length sections of transmission line, which in this case are of coaxial cable sections 44, 46 and 48. As far as possible the electrical path lengths from the aerials to the output cable 42 are made the same in order to avoid phase difference errors being introduced in the transmission of signals to the receiver 50.

To achieve the isolation of the two non-selected aerials, each of the coaxial cables 44, 46 and 48 is made an electrical eighth of a wavelength in length between the dipole feed-point and the switching point. The unit being described is designed primarily for operation in the 156 MHz band so that the length of the cable sections is chosen for that frequency. However, it has been found in practice that unit as a whole

performs adequately when direction finding in the 121 MHz band. Measures are taken in conjunction with the cable sections to ensure that the two non-selected aerials do not affect the selected one. These measures will be explained with reference to Fig. 4.

Fig. 4 shows the switching arrangement for one dipole A. The other two dipoles are switched in the same manner and for convenience of layout and to maintain equality of path length from each aerial through to cable 42, the cable sections and the switching diodes to be described can be physically laid out on a PCB in the geometry indicated in Fig 3.

The switch 40 is realised in the circuit illustrated in Fig. 4 by use of respective PIN diodes having say their anodes connected in common and their cathodes providing the three input terminals for the aerial signals. Thus in Fig. 4, a PIN diode 60 is connected in series between the inner conductor of the coaxial cable section 44 and the inner conductor of output coaxial cable 42. Bias for switching the PIN diode 60 is provided from a positive rail (+) connected to the common anode point through appropriate RF isolation here indicated as a radio frequency choke RFC. The bias current path extends through the diode to a series connection of an inductor L and a switching device shown as a transistor T. The diode 60 is forward biased by turning ON transistor T. When the diode 60 is conducting a low impedance path (that of cables 44 and 42) extends from the aerial A through the diode 60 to the receiver to be described. The inductor L in shunt across this path has an impedance sufficiently high to essentially not affect signal flow.

When transistor T is turned OFF, thereby turning OFF diode 60 to break the signal path the inductor L is RF connected across the cable section 44 at its inboard end remote from dipole A. This RF connection is made through a capacitor C by-passing the non-conducting transistor T. The inductor co-acts with the cable section 44 to isolate the dipole A from the one, say B, of the other two dipoles that is connected to cable 42 as dipole A is disconnected.

The other dipole C, disconnected from cable 42, is also isolated in the same manner as dipole A. It is theorized that the isolation of a dipole such as the dipole A is achieved by the inductor L being so chosen that the capacitive reactance of the eighth wavelength section is resonated using the inductor to create a high impedance of a non-selected dipole, so that it is effectively open circuit. In the unit under discussion, this isolation is optimized at 156 MHz. The isolation technique described also aids in preventing any stray signal on the outer of the coaxial cable section from passing onto the PCB as interference. The above described measures may be usefully adopted with dipoles which are off-resonance (long or short) at the design frequency of 156 MHz.

Thus the aerial-cable-switch combination provides the ability to select one dipole for receiving without being affected by the other two dipoles.

The control of the switch 40, and specifically of the transistor T, is exercised to select the dipoles in a repeated sequence using the dipole A as a phase reference. The dipoles are switched in a sequence: A-B, A-C, A-B, A-C and so on.

If the coaxial cable sections 44, 46, 48 have a typical

velocity factor of 0.67, then the length of each is about 16 cms at 156 MHz. This leads to an aerial spacing S of about 28 cms.

The processing of the signals from the three dipoles will now be described.

The incoming signal on cable 42 from a selected dipole is applied to a conventional receiver 50 which can be used for normal monitoring of the aircraft and marine band channels. There are numerous integrated circuits available to enable reception of both these bands and a superheterodyne receiver is assumed so that the phase information can be preserved through to a suitable I.F. stage at which the signal can be picked off for processing. The signal is taken from say an I.F. at 455kHz and applied to a phase-sensitive circuit 52 that detects the phase of the I.F. signal. Specifically circuit 52 locks an internal voltage control oscillator (VCO) to the I.F. signal by use of a phase detector for the two signals which controls the VCO in an integrating phase-lock loop (PLL) which provides zero phase error. The control voltage V at the output of the integrator in the PLL is proportional to phase. When the PLL locks to the I.F. signal while dipole A is selected it provides a voltage V_a. When dipole B is selected the integrator voltage changes to V_b. What is important is the phase difference β_1 which is represented by the voltage difference V_a-V_b. Likewise in switching between dipoles A and C, the phase difference β_2 is represented by a voltage difference V_a-V_c.

The analogue voltages from the PLL 52 are applied to an analogue-to-digital converter (ADC) 54 to produce the

numerical voltage values in digital form suitable for processing by a microprocessor 56.

From the digitized voltage values, the microprocessor calculates the phase difference values β_1 and β_2 including the sign of the values.. The bearing θ is then calculated using the equation previously given, namely

$$\theta = \tan^{-1} [\sqrt{3} . \frac{\beta_2 - \beta_1}{\beta_2 + \beta_1}]$$

Calculation according to this equation has the advantage that frequency or wavelength does not enter the equation so it is equally applicable to the phase difference information derived from an incoming signal at 156 MHz as to one at 121 MHz.

In practical use of the hand-held unit, it is going to be held with the unit's heading near zero bearing. In this way the search vessel, e.g. an inflatable boat, can be used to "run down" to person in the water.

It has been found that if the dipole array is designed for the 156 MHz marine band it still has adequate sensitivity (provides adequate range) for the 121 MHz aeronautical band.

The microprocessor 56 synchronizes with a control pulse generator 58 which sends control pulses to the switch 40 to cause the switch to select the dipoles A, B and C in the desired A, B, A, C, - sequence. The control pulses include a synchronizing pulse, e.g. a longer pulse, to ensure the processing in the microprocessor is synchronized with the aerial selection. This is generated in response to a sync pulse from the microprocessor and recognized by the circuitry that controls the PIN diodes constituting switch 40 to set the

switch to a given position, e.g. selecting dipole A. Typically the aerials are switched at around 1kHz so that each aerial is selected for 1mS. This provides ample time for the PLL 52 to lock to the I.F. signal and for the digital values to be derived.

It will be understood that the aerial elements need not be dipoles. The array 10 itself need not be arranged in an equilateral triangle. A similar form of expression to the equation given above can be derived for any isosceles triangle symmetrical with respect to the bisector of the vertex angle i.e. the angle between the two equal sides. Other triangles require more complicated calculation.

The number of aerial elements in the array can be increased, particularly by using odd numbers of elements - 5, 7 etc. Enhanced accuracy can be achieved but at the cost of complexity and bulk.

It will be realised that a microprocessor algorithm can be produced to obtain the bearing θ clockwise or counter-clockwise with reference to the heading H.

Claims

1. Direction finding (DF) apparatus comprising:

at least three spaced aerial elements for receiving incoming signals;

switching means for selectively connecting said aerial elements to a receiver operable to select an incoming signal whose bearing is to be determined;

control means for controlling the operation of the switching means;

phase-sensitive means connected to a stage of said receiver at which the received signal has a phase dependent on the phase of the incoming signal induced in the selected aerial, said phase-sensitive means providing an output signal representing the phase of the signal at the selected aerial;

and processing means responsive to the respective output signals from said phase-sensitive means representing the phases of the incoming signal at the aerial elements to derive phase-difference signals representing the phase difference of the incoming signal between pairs of the aerial elements and to use said phase-difference signals to determine the bearing of the incoming signal.

2. DF apparatus as claimed in Claim 1 in which said receiver is a superheterodyne receiver and said phase-sensitive means is connected to an intermediate frequency (I.F.) stage in said receiver.

3. A DF apparatus as claimed in Claim 2 in which said phase-sensitive means comprises a voltage-controlled

oscillator (VCO) in a phase-lock loop (PLL), preferably an integrating PLL, lockable to the incoming signal in said IF stage to provide a phase dependent output signal having an amplitude dependent on the phase of the incoming signal.

4. A DF apparatus as claimed in Claim 3 in which said phase-dependent output signal is an analogue signal and processing means comprises an analogue-to-digital converter to convert the phase-dependent output signal to digital form, and said processing means comprises a digital processor for processing the digitised output signal.

5. A DF apparatus as claimed in Claim 3 in which said processing means comprises a microprocessor.

6. A DF apparatus as claimed in any preceding claim in which there are three aerial elements arranged at the apexes of an isosceles triangle, and said control means is arranged to control the selective switching of the three aerial elements in the repeated sequence: vertex element (common to the two equal sides), first of the two other elements, vertex element, and second of the other two elements.

7. A DF apparatus as claimed in Claim 6 in which processing means is operable to calculate the bearing of the incoming signal with respect to a projection of the bisector of the vertex angle by an equation of the form

$$\theta = \tan^{-1}[k(\beta_1-\beta_2)/(\beta_1+\beta_2)]$$

where β_1 and β_2 are the respective phase differences between the vertex and first aerial elements and the vertex and

second aerial elements, and k is a constant dependent on the angles of an isosceles triangle and has a value of $\sqrt{3}$ for an equilateral triangle.

8. A DF apparatus as claimed in any one of Claims 1 to 5 in which there are three aerial elements arranged at the apexes of an equilateral triangle, and said control means is arranged to control the selective switching of the three aerial elements in the repeated sequence first element, second element, first element, and third element.

9. A DF apparatus as claimed in Claim 8 in which said processing means is operable to calculate the bearing of the incoming signal with respect to a projection of the bisector of the angle at the apex at which the first aerial element is located by an equation of the form

$$\theta = \tan^{-1}[\sqrt{3}(\beta_1-\beta_2)/(\beta_1+\beta_2)]$$

where β_1 and β_2 are the respective phase differences between the first and second pair of aerial elements and the first and third pair of aerial elements.

10. A DF apparatus as claimed in any one of Claims 1 to 9 in which said aerial elements are connected to said switching means through transmission line sections of equal electrical length.

11. A DF apparatus as claimed in Claim 10 in which said switch means is connected to said receiver through a common-length of transmission line.

12. A DF apparatus as claimed in Claim 10 or 11 in which said transmission line sections are one-eighth wavelength

long.

13. A DF apparatus as claimed in Claim 12 in which each transmission line section is terminated at the switch means by an inductor which when the transmission line section is not selected co-acts with the transmission line to isolate the associated aerial from influencing the selected aerial element.

14. A DF apparatus as claimed in any preceding claim in which each aerial element comprises a dipole.

15. A DF apparatus as claimed in any preceding claim in which said aerial elements are identical.

16. A DF apparatus as claimed in any preceding claim further comprising a housing to which each aerial element is mounted, the remainder of the DF apparatus being contained within the housing, a handle attached to the housing for carrying the housing; and a display giving information on the determined bearing mounted to be visible from outside the housing by a person carrying same by the handle.

17. Direction finding (DF) apparatus comprising:

switching means having at least three input terminals to which respective aerials are connectable and operable for selectively connecting said input terminals to a receiver operable to select an incoming signal whose bearing is to be determined;

control means for controlling the operation of the switching means;

phase-sensitive means connected to a stage of said

receiver at which the received signal has a phase dependent on the phase of the selected incoming signal at the selected input terminal, said phase-sensitive means providing an output signal representing the phase of the selected incoming signal at the selected input terminal;

and processing means responsive to the respective output signals from said phase-sensitive means representing the respective phases of the selected incoming signal at the input terminals to derive phase-difference signals representing the phase difference of the selected incoming signal between pairs of the input terminals and to use said phase-difference signals to determine the bearing of the incoming signal.

18. DF apparatus as claimed in Claim 17 having one or more of the features claimed in Claims 2 to 5.

19. An aerial system for a direction finding apparatus comprising:

at least three aerial elements,

a switch arrangement having a respective input terminal for each aerial element and a common output terminal and operable to connect a selected input terminal to the output terminal;

the feed point of each aerial element being connected to its respective switch input terminal by a section of transmission line one side of which is connected to the respective input terminal, and

a respective reactance connected at each switch input terminal to be connected across the associated transmission

line section when said switch arrangement is an operational state in which the input terminal is not connected to the output terminal.

20. An aerial system as claimed in Claim 19 in which said switch arrangement comprises a respective PIN diode connected in series between each switch input terminal and the output terminal, and a respective switching device controlling the biasing of the associated PIN diode, and the associated reactance comprises an inductor connected in the bias current path of the associated PIN diode.

21. An aerial system as claimed in Claim 20 in which each inductor is connected between the respective input terminal of the switch arrangement and the associated switching device.

22. An aerial system as claimed in any one of Claims 19 to 21 in which said aerial elements are dipoles.

23. An aerial system as claimed in any one of Claims 19 to 22 in which there are three aerial elements arranged at the vertices of an isosceles or equilateral triangle.

24. A direction finding apparatus comprising

an aerial array of three aerial elements located at the apexes of an isosceles or equilateral triangle,

means connected to said aerial elements and responsive to an incoming signal wavefront to detect the phases of the respective signals induced in the aerial elements and to derive a first signal representing the phase difference between one of said aerial elements (said one aerial element being at the apex between the two sides of equal

length in the case of an isosceles triangle) and a second of said aerial elements, and a second signal representing the phase difference between said one aerial element and the third of said aerial elements,

and processing means for deriving a bearing θ for the direction of the incoming wavefront which, when referred to a heading aligned with the bisector of the angle at the apex at which said one aerial is located, is of the form

$$\theta = \tan^{-1}[k(\beta_1-\beta_2)/(\beta_1+\beta_2)]$$

where k is a constant dependent on the angles of an isosceles triangle and has a value of $\sqrt{3}$ for an equilateral triangle, and β_1 and β_2 are the phase difference values represented by said first and second signals respectively.

The Patent Office

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Application No: GB 9823063.4
Claims searched: 1-18 & 24

Examiner: Robert Shorthouse
Date of search: 8 May 2000

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H4D (DFC)

Int Cl (Ed.7): G01S 3/04, /48

Other: Online: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2261788 A	(IST) See figs. 1,2,4 and abstract	1, 14, 15, 17
X	WO 97/42518 A1	(THOMSON-CSF) See abstract	1, 2, 14, 15, 17, 18
X	US 5657027	(GUYMON) See column 1 line 50 - 57	1, 14, 15, 17
X	US 4626859	(STANSFIELD) See fig. and column 2 lines 17 - 41	1, 6, 8, 14, 15, 17
X	DE 4318548 A1	(ROHDE) See column 2 lines 13-29	1, 6, 8, 14, 15, 17

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
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E Patent document published on or after, but with priority date earlier than, the filing date of this application.